

Measurement of electron lifetime using LongBo TPC data

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Abstract

We present the measurement of electron attenuation using the cosmic ray muon data taken with the LongBo TPC in the LAPD cryostat. We also compare the results with the measurements using purity monitors.

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1 Introduction

When cosmic ray muons pass through the liquid argon, they deposit energy through ionization. The ionization electrons are drifted by the electric field and collected by the wire planes. On average, the variation of the energy deposition along the muon track is small since the muons are in the minimal ionizing region. By examining the signal recorded by each wire as a function of electron drift time, one can measure the attenuation of ionization electrons along the drift distance and determine the electron lifetime. This method was used by ArgoNeuT to derive the electron lifetime [1].

The LongBo TPC was taking cosmic data from early 2013 till September 2013. We analyzed cosmic ray muon data taken between April 8 (Run 288) and June 21

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(Run 360). This corresponds to a full circle of LAPD running, from liquid pump start to pump end. The high voltage we applied to the cathode was 70 kV during this period, which produced an electric field of 350 V/cm in the TPC volume. In this note, we present results on the measurements of electron lifetime using data taken in this period.

2 Reconstruction

There are 491 966 triggered events during this run period. We use LARSOFT software package v02_00_01 to reconstruct cosmic ray muon events. The automated reconstruction procedure first does signal shaping by applying deconvolution to the raw wire signals, and then finds hits and defines clusters using reconstruction module Cluster-Crawler. Three dimensional tracks are constructed from pairs of line-like clusters in each plane using reconstruction module CosmicTracker. 274 491 events have at least one reconstructed track (212 626 events with exactly one reconstructed track). Fig. 1 shows one example event after the full reconstruction chain.

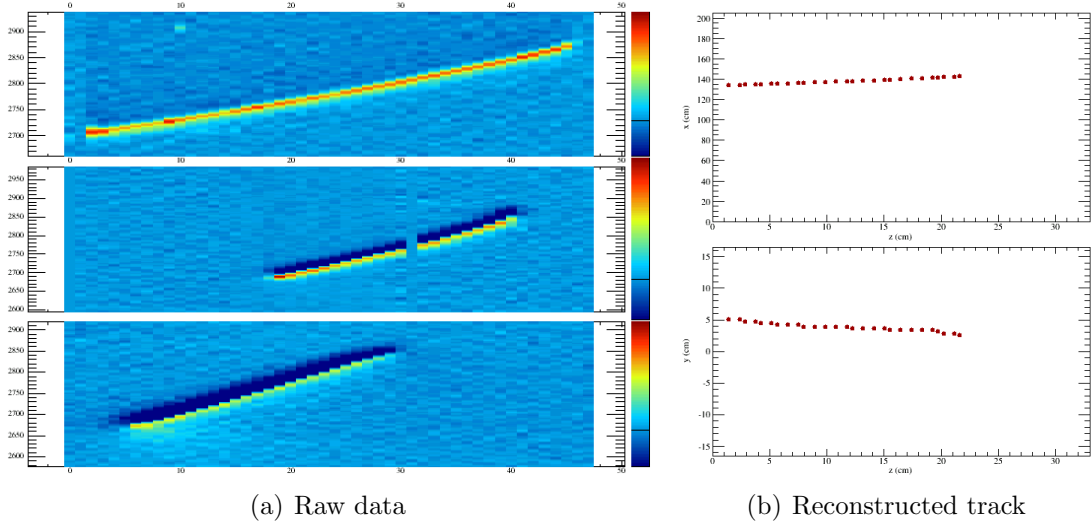


Figure 1: Run 293 Event 2225. (a) Drift time vs wire ID for raw wire signal from 3 wire planes. Red color represents high positive charge and blue color represents high negative charge. (b) Reconstructed track points in the x-z and y-z projections.

In this analysis we only consider events with exactly one reconstructed track that has at least 5 reconstructed space points. We do not use events with multiple muon tracks because we cannot determine the track start time (t_0) for each track. Fig. 2 shows the angular distributions of the reconstructed tracks. The track angle is determined by the reconstructed track start and track end assuming the track is a straight line. The θ angle is peaked around 60° and the ϕ angle is determined by the trigger counter locations. Fig. 3 shows the reconstructed track start point x (drift direction) vs θ angle.

The muons normally enter the TPC in the middle, but they can be close to the wire planes and cathode.

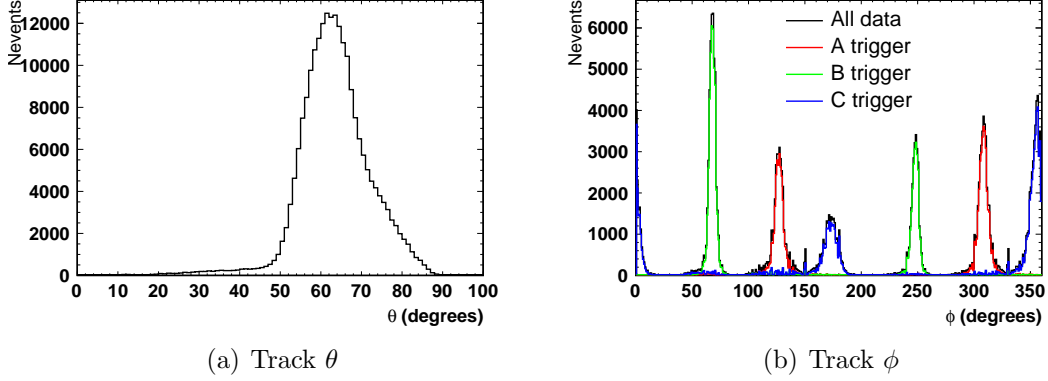


Figure 2: Reconstructed track angles: (a) θ - with regards to the vertical direction; (b) ϕ , events taken with different triggers have distinct ϕ distributions.

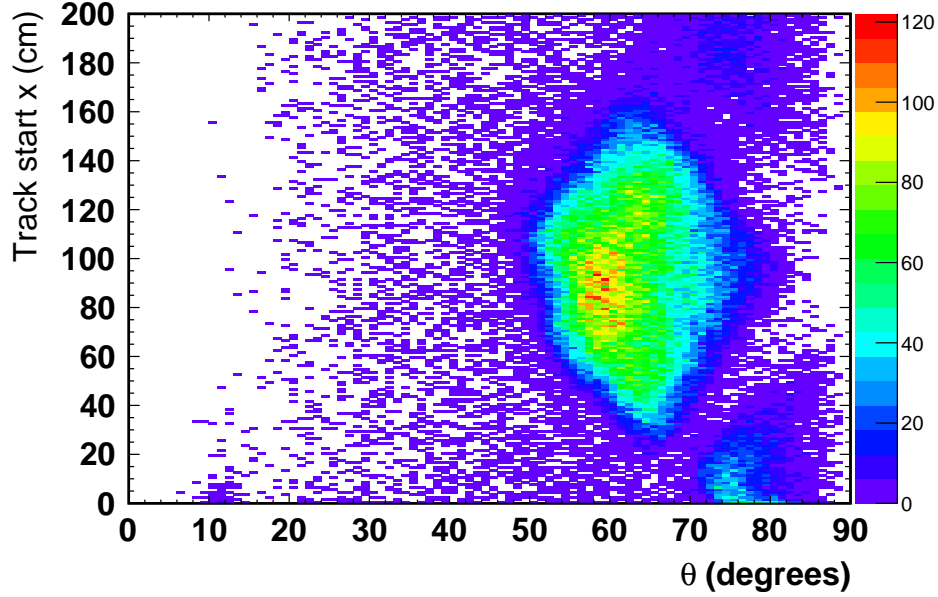


Figure 3: Reconstructed track start point in the drift direction (x) vs track angle (θ).

3 Lifetime Measurement

We use clean muon tracks to measure electron lifetime in liquid argon. We first select events with well reconstructed and clean tracks:

- The RMS distance of reconstructed space points with respect to a straight line determined by track start and end should be less than $\sqrt{40}$ mm.
- The number of hits that are not associated with the reconstructed track should be less than 11.
- Track length is required to be greater than 15 cm. The track length is defined as the distance between reconstructed track start and end points.
- Track length $\times \cos \phi_{\text{track}}$ is required to be greater than 10 cm. This is the projection along the collection plane trigger direction.
- $50^\circ < \theta_{\text{track}} < 70^\circ$.

We then select hits associated with the tracks:

- We only use hits on the collection wire plane.
- We do not use the first hit or the last hit on a track.
- There should be only one hit on each wire.
- If there is one hit on each of three continuous wires that has $dQ/dx > 2000$ ADC/cm, we do not use those three hits. This is meant to remove delta rays.

For each selected hit, we look at raw digits for that hit in the region $[t - 3 \times \sigma, t + 3 \times \sigma]$, where t is the reconstructed hit time and σ is the reconstructed hit width. We first find the peak of the raw digits (in ADC), we then sum all the digits above a threshold of 10% of the peak to get the charge of the hit. By using raw digits we remove uncertainties introduced by signal shaping in the hit reconstruction. We then divide the hit charge by the track pitch, which is defined as the dot product of the track direction and wire pitch (in the direction normal to the wire direction in the wire plane), to get dQ/dx for the hit.

Figure 4(a) shows hit dQ/dx vs electron drift time distribution using data taken in a 2-hour window. Fig. 4(b) shows dQ/dx distribution for hits with drift time between 456 and 482 μs (shaded area in Fig. 4(a)). We fit a Landau convoluted with Gaussian function to the dQ/dx distribution. An example fit is shown in Fig. 4(b). Fig. 4(c) shows the MPV (most probable value) from the Landau fit as a function of drift time. The signal decreases as drift time increases as expected. We fit an exponential function to the data points:

$$dQ/dx = e^{-at_d+b} \quad (1)$$

where t_d is the drift time and a is the attenuation constant (negative of the slope from exponential fit). Fig. 5 shows $dQ/dx_0 = dQ/dx(t = 0) = e^b$ as a function of time and it is relatively flat. The attenuation constant is corrected for electron diffusion, which is described in Appendix A.

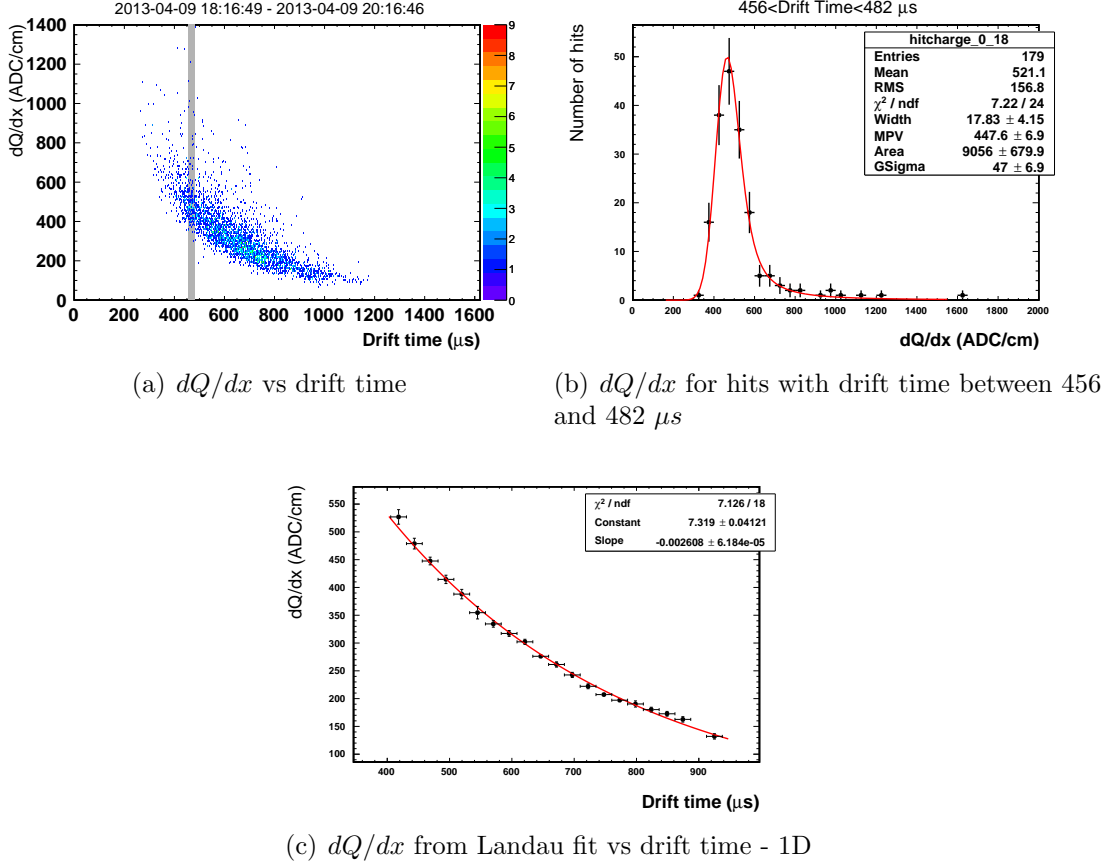


Figure 4: dQ/dx distributions of hits using data taken in a 2-hour window. (a) Scatter plot of dQ/dx as a function of electron drift time; (b) dQ/dx distribution for hits with drift time between 456 and 482 μs ; (c) dQ/dx from Landau fit as a function of drift time.

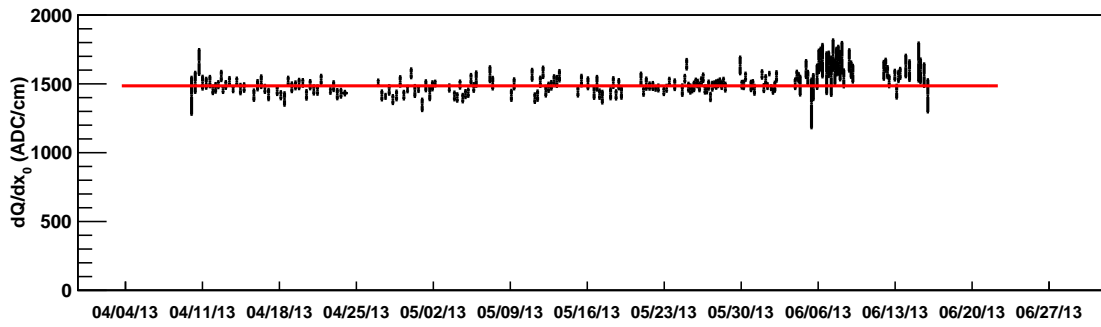


Figure 5: dQ/dx_0 as a function of time.

LAPD reported the measurement of electron attenuation using purity monitors [2]. The result was presented as Q_A/Q_C as a function of time, where Q_A/Q_C represents the

fraction of electrons generated at the purity monitor cathode that arrive at the anode. It is determined by the electron drift time (t_d) and electron lifetime (τ) or attenuation constant (a):

$$Q_A/Q_C = e^{-t_d/\tau} = e^{-at_d}. \quad (2)$$

In order to compare the measurement using TPC data with the measurement using purity monitors, we calculate the equivalent Q_A/Q_C using the attenuation constant measured by the TPC data and $t_d = 0.38$ ms, which is the electron drift time from the cathode to the anode grid in the purity monitor. Fig. 6 shows the comparison between Q_A/Q_C measured by the purity monitors and the calculated Q_A/Q_C using attenuation constant measured using the TPC data. The statistical errors from the original landau fits are propagated correctly through the attenuation fits to Fig. 6, and are smaller than the red points.

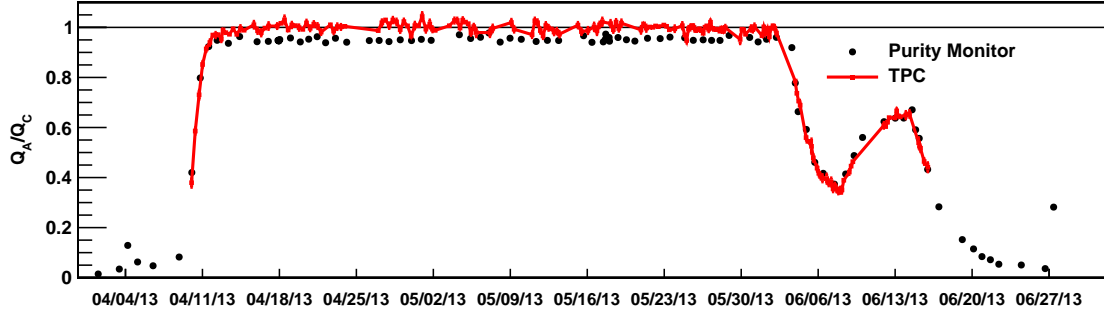


Figure 6: Comparison between Q_A/Q_C measured by the purity monitors and the calculated Q_A/Q_C using attenuation constant measured using the TPC data.

4 Summary

In summary, we measure the electron attenuation using the cosmic muons accumulated in the LongBo TPC. The resulting attenuation measurement is in a good agreement with the measurement using purity monitors when the attenuation is greater than 10% in the purity monitor. When the liquid argon is very purity (attenuation less than 10%) there is a noticeable difference between the two measurements most likely caused by systematic effects in both instruments.

A Correction for Diffusion

While we were measuring electron attenuation using cosmic ray muons, we observed an electron “gain” when the liquid argon was very pure, i.e. the signal is higher at longer drift time, which suggests not only the electron absorption is negligible, but

also the signal is getting bigger as the electrons travel toward the wire planes. We have investigated many systematic effects that may cause this “negative lifetime” artifact. The most likely explanation is electron diffusion.

We simulated a sample of 10 000 single muons at a fixed momentum of 6 GeV/ c using the LongBo TPC geometry. The vertex x (drift direction) is uniformly distributed between 50 and 150 cm while $y = z = 0$ cm are on the edge of the TPC. The θ angle is uniformly distributed between 50° and 70° while the ϕ angle is fixed at 0° . GEANT4 is used to simulate particle propagation in the liquid argon. The electron drifting and signal collection is simulated using LARSOFT taking into account of recombination, attenuation and diffusion.

We then run the same reconstruction and analysis chain on the simulated events. Fig. 7(a) shows dQ/dx as a function of drift time when we use the default diffusion simulation:

$$\sigma_L = \sqrt{2t_d D_L} \quad (3)$$

$$\sigma_T = \sqrt{2t_d D_T} \quad (4)$$

where t_d is the electron drift time, D_L and D_T are the longitudinal and transverse diffusion constants:

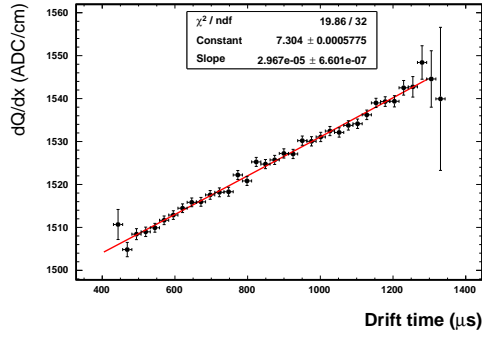
$$D_L = 6.2 \times 10^{-9} \text{cm}^2/\text{ns} \quad (5)$$

$$D_T = 16.3 \times 10^{-9} \text{cm}^2/\text{ns} \quad (6)$$

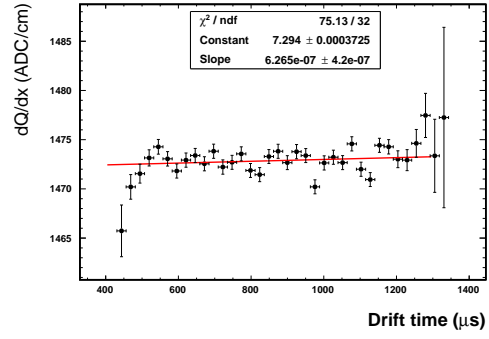
We fit an exponential function to the dQ/dx distribution and the fitted slope is clearly positive. Fig. 7(b) shows the similar distribution with both longitudinal and transverse diffusion turned off ($D_L = D_T = 0$). The fitted slope is consistent with being 0. We take the difference between the two slopes and use it to correct data for diffusion effect. The difference (positive) is added to the measured attenuation constant. We also generated MC with only transverse diffusion ($D_L = 0, D_T = \text{default}$) and with only longitudinal diffusion ($D_T = 0, D_L = \text{default}$) and the positive slope is caused completely by the transverse diffusion. The transverse diffusion makes the electrons smeared between neighboring wires

References

- [1] C. Anderson, M. Antonello, B. Baller, T. Bolton, C. Bromberg, F. Cavanna, E. Church and D. Edmunds *et al.*, JINST **7**, P10019 (2012) [arXiv:1205.6747 [physics.ins-det]].
- [2] M. Adamowski, B. Carls, E. Dvorak, A. Hahn, W. Jaskierny, C. Johnson, H. Jostlein and C. Kendziora *et al.*, JINST **9**, P07005 (2014) [arXiv:1403.7236 [physics.ins-det]].



(a) Default diffusion



(b) No diffusion

Figure 7: Simulated dQ/dx vs drift time with (a) Default diffusion; (b) No diffusion.